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औद्योगिक रोबोट सुरक्षा का विकास

Indian Standard

MANIPULATING INDUSTRIAL ROBOTS — SAFETY

ICS 25.040.30

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Price Group 5

Robotics Sectional Committee, PE 18

NATIONAL FOREWORD

This Indian Standard which is identical with ISO 10218 : 1992 'Manipulating industrial robots – Safety issued by the International Organization for Standardization was adopted by the Bureau of Indian Standards on the recommendation of the Robots Sectional Committee and approval of the Production Engineering Division Council.

The text of the ISO standard has been approved as suitable for publication as Indian Standard without deviation. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following :

a) Wherever the words 'International Standard' appear referring to this standard, they should read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker in the International Standard while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards which are to be substituted in their place are listed below along with their degree of equivalence for the editions indicated :

International Standards	*Corresponding Indian Standards*	*Degree of Equivalence*
ISO 8373 : 1994 (B) Manipulating industrial robots — Vocabulary	IS 13700 Manipulating industrial robots — Vocabulary	Identical
ISO 9946 : 1991 Manipulating industrial robots — Presentation of characteristics	IS 14531 : 1998 Manipulating industrial robots — Presentation of characteristics	Equivalent

The technical committee responsible for the preparation of this standard will review the provisions of the following IEC/ISO standards and will decide about their acceptance for use in conjunction with this standard :

International Standards	*Corresponding Indian Standards*	*Degree of Equivalence*
IEC 204-1 Electrical equipment of industrial machines—Part 1 : General requirements	Nil	—
ISO 6385 : 1981 Ergonomic principles of the design of work systems	Nil	—

AMENDMENT NO. 1 MAY 2002
TO
IS 14530 : 1998/ISO 10218-1992 MANIPULATING INDUSTRIAL ROBOTS — SAFETY

(*Cover page 2, National Foreword, para 3, under the head 'Corresponding Indian Standards'*) — Substitute 'IS 14662 : 1999' *for* 'IS 13700'.

(PE 18)

Reprography Unit, BIS, New Delhi, India

Indian Standard

MANIPULATING INDUSTRIAL ROBOTS — SAFETY

1 Scope

This International Standard provides guidance on the safety considerations for the design, construction, programming, operation, use, repair, and maintenance of manipulating industrial robots and robot systems as defined in clause 3. It does not apply to other types of robots although the safety principles established in this International Standard may be utilized for these other types.

NOTE: For the purpose of this International Standard, the term "robot" means manipulating industrial robot.

For systems comprising multiple robots and/or associated material handling equipment or mobile robots, this International Standard may be used for the robot system portion of the equipment.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 204-1: —[1], *Electrical equipment of industrial machines – Part 1: General requirements.*

ISO 6385: 1981, *Ergonomic principles of the design of work systems.*

ISO/TR 8373: 1988, *Manipulating industrial robots - Vocabulary.*

ISO 9946: 1991. *Manipulating industrial robots - Presentation of characteristics.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 General terms

3.1.1 person: Any individual.

3.1.2 personnel: Persons specifically employed and trained in the use and care of a robot system.

3.2 Specific terms

NOTE : The terms which are referenced to ISO/TR 8373 are those which have been duplicated from that document.

3.2.1 arm [primary axes]: An interconnected set of links and powered joints comprising members of the longitudinal shape which supports, positions, and orientates a wrist and/or end effector.
[ISO/TR 8373:1988, 3.2]

3.2.2 automatic mode: The operating mode in which the robot control system can operate in accordance with the task program.
[ISO/TR 8373:1988, 5.3.8.1]

3.2.3 enabling device: A manually operated device intended to allow robot motion only while the device is held in a predetermined position.

3.2.4 guard: A machine component specifically used to provide protection by means of a physical barrier. Depending on its construction, a guard may be called casting, cover screen, fence, door, enclosing guard, barrier, etc.

3.2.5 hazard: A situation that may give rise to an injury or damage to health.

3.2.6 hazardous condition/motion: Any condition/motion of the robot or robot system that can cause injury to persons.

3.2.7 hold-to-run control: A control which allows movements exclusively during the manual actuation of that control and that causes these movements to stop as soon as it is released.

3.2.8 interlock (for safeguarding): An arrangement that interconnects guard(s) or device(s) with the robot control and/or power system of the robot and its associated equipment.

3.2.9 local control: A state of the robot in which it is operated from the control panel at the robot system installation or teach pendant.

3.2.10 lockout/tagout: The placement of a lock and/or tag on the energy isolating device (e.g. disconnecting means) in the 'OFF' or 'OPEN' position indicating that the energy isolating device or the equipment being controlled shall not be operated until the removal of the lock/tag.

3.2.11 manipulating industrial robot: An automatically controlled, reprogrammable, multi-purpose, manipulative machine with several degrees of freedom, which may be either fixed in place or mobile for use in industrial automation applications.

NOTE: The following is an explanation of terms used in the above definition:

- reprogrammable: whose programmed motions or auxiliary functions may be changed without physical alterations;
- multi-purpose: can be adapted to different applications with physical alterations;
- physical alteration means alteration of the mechanical structure or control system except for changing programming cassettes, ROMs, etc.

[ISO/TR 8373:1988, 2.3]

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[1] To be published. (Revision of IEC 204-1:1981.)

3.2.12 manual mode: The operating mode in which the robot can be operated by, for example, pushbutton or joystick and that excludes automatic operation.

3.2.13 maximum space: The space which can be swept by the moving parts of the robot as defined by the manufacturer plus the space which can be swept by the end effector and the workpiece (see figure 1).

3.2.14 (teach) pendant: A hand held unit linked to the control system with which the robot can be programmed (or moved).
[ISO/TR 8373:1988, 5.8]

3.2.15 presence sensing device: A device that has a sensing field or space which will detect any intrusion into that field or space.

NOTE: Presence sensing devices include but are not limited to light screens, electromagnetic fields, pressure sensitive devices, ultrasonic and infrared devices, and image processing systems.

3.2.16 programmer: A competent person designated to prepare the task program.
[ISO/TR 8373:1988, 2.9]

3.2.17 reduced speed: A single selectable velocity provided by the robot supplier which automatically restricts the robot velocity to one intended to allow sufficient time for persons either to withdraw from hazardous motions or to stop the robot.

3.2.18 restricted space: The portion of the maximum space that is restricted by limiting devices that establish limits that will not be exceeded in the event of any foreseeable failure of the robot system (see figure 1).

NOTE: The maximum distance that the robot can travel after the limiting device is actuated is considered the basis for defining the restricted space.
[ISO/TR 8373:1988, 4.5.3]

3.2.19 risk: A combination of the probability of injury occurring and the degree of the injury.

3.2.20 robot system: A robot system includes:
- the robot (hardware and software) consisting of the manipulator whether mobile or not, power supply, and control system;
- the end effector(s);
- any equipment, devices, or sensors required for the robot to perform its tasks;
- any communication interface that is operating and monitoring the robot, equipment, or sensors, as far as these peripheral devices are supervised by the robot control system.

[ISO/TR 8373:1988, 2.6]

3.2.21 safe working procedure: A specified procedure intended to reduce the possibility of injury while performing an assigned task.

3.2.22 safeguard: A guard or device designated to protect persons from a hazardous point or area.

3.2.23 safeguarded space: The space determined by the safeguards (see figure 1).

NOTE: The safeguarded space includes the restricted space.

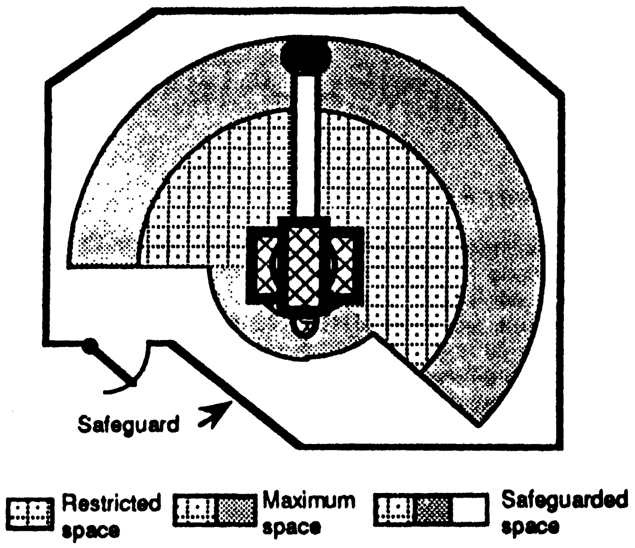


Figure 1 – Example of restricted space and safeguarded space

3.2.24 safeguarding: Methods for protection of person(s) using guards, devices, and safe working procedures.

3.2.25 trouble shooting [fault finding]: The act of methodically determining the reason that a robot system has failed to perform the task or function as intended.

4 General considerations

4.1 General

It is recognized that the operational characteristics of robots can be significantly different from those of other machines and equipment. Robots are capable of high energy movements through a large volume beyond the base of robots. The pattern and initiation of movement of the robot arm are difficult to predict and can vary because of variables in product and environmental conditions.

Some maintenance and programming personnel are at times required to be within the restricted space while power is available to the machine actuators. The restricted space of the robot can overlap a portion of the restricted space of other robots or work zones of other industrial machines and related equipment. This can give rise to hazards of impact, trapping, or flying objects released by the gripper.

The type of robot, its application, and its relationship to other industrial machines and related equipment will influence the design and the selection of the safeguarding methods. These need to be suitable for the work being done and permit, where necessary, teach programming, setting, maintenance, program verification, and trouble shooting operations to be carried out safely. Many installations will require close approach for such work.

The chosen methods should be appropriate for the hazards associated with the robot installation. Before designing or selecting appropriate safeguarding methods, it will be necessary to identify the hazards and to assess the associated risks.

Technical measures for the prevention of accidents are based upon two fundamental principles:

- the absence of persons in the safeguarded space during automatic operation;
- the elimination of hazards or at least their reduction during interventions (e.g. teaching, program verification) in the safeguarded space.

The observance of these principles involves several actions:
- the creation of a safeguarded space and a restricted space;
- a design of the robot system such as to allow the maximum number of tasks to be performed from outside the safeguarded space;
- provision of compensatory means of safety in case of interventions within the safeguarded space.

4.2 Safety analysis

To carry out a safety analysis, it is necessary to
- define the required tasks for the foreseeable applications including an evaluation of the need for access or close approach,
- identify the sources of hazards including the fault and failure modes associated with each task (see 4.2.1),
- evaluate and assess the risks (see 4.2.2),
- consider safety strategies which minimize the risks to an acceptable level (see 4.2.3),
- select the safeguarding methods consistent with the required task and the acceptable level of risks (see 7.3, 7.4, and 7.5), and
- assess the achieved levels of safety integrity for the safety and ensure that these levels are acceptable (see 4.2.3).

4.2.1 Sources of hazards

Hazards can arise from the robot system itself, from its association with other equipment, or from interaction of persons with the robot system. Examples of sources of hazards are (but are not limited to)

a) failures or faults of
   1) protective means (e.g. devices, circuits, components) including removal or disassembly;
   2) power sources or means of distribution;
   3) control circuits, devices, or components;

b) moving mechanical components causing trapping or crushing
   1) individually (by themselves);
   2) in conjunction with other parts of the robot system or other equipment in the work area:

c) stored energy
   1) in moving parts;
   2) in electrical or fluidic power components;

d) power sources
   1) electrical;
   2) hydraulic;
   3) pneumatic;

e) hazardous atmospheres, materials, or conditions:
   1) explosive or combustible;
   2) corrosive or aggressive;
   3) radioactive;
   4) extreme high or low temperature;

f) noise (acoustical);

g) interferences:
   1) electromagnetic, electrostatic, radio frequencies;
   2) vibration, shock;

h) human errors in
   1) design, development, and construction including ergonomic considerations;
   2) installation and commissioning including access, lighting, and noise;
   3) functional testing;
   4) application and use;
   5) programming and program verification;
   6) set-up including work handling/holding and tooling;
   7) trouble shooting and maintenance;
   8) safe working procedures;

i) moving, handling, or replacing of the robot system or associated components.

4.2.2 Risk assessment

The size, capacity, and speed of robots vary greatly. In addition, there are many different potential applications for robots. Consequently, there will be different hazards and different levels of risk. The risks during the installation, programming, operation, use, trouble shooting, and maintenance of the robot system shall be assessed.

Particular attention should be paid to the need for close approach to the robot when power is available at the machine actuators. The need for close approach is recognized in some exceptional circumstances and shall be provided for in the design and application of appropriate safeguards. Attention should be paid to the fact that the final position of the robot after an emergency stop cannot be adequately determined owing to the kinetic energy involved.

4.2.3 Safety strategy for selection of safety measures

Safety measures are a combination of the measures incorporated at the design stage and those measures required to be implemented by the user.

The design and development of the robot system shall be the first consideration while still maintaining an acceptable level of performance. Where this is not possible, safeguarding shall be considered in such a manner that the flexibility of the robot system in its application is retained. Safeguarding includes the use of safeguards, awareness means, and safe working procedures (see 7.3, 7.4, and 7.5).

5 General design requirements

5.1 Failure to safety

The robot system shall be designed, constructed, and implemented so that in case of a foreseeable failure of any single component, whether electrical, electronic, mechanical, pneumatic, or hydraulic, safety functions are not affected or when they are, the robot system is left in a safe condition. Safety functions include but are not limited to
- limiting range of motion,
- emergency and safety stopping,
- reduced speed, and
- safeguard interlocking.

The requirements of IEC 204-1 regarding control functions in case of failure shall apply.

5.2 Electrical equipment

The application of the electrical equipment of the robot and robot system shall be in accordance with IEC 204-1.

5.3 Power supply

The power supply and grounding (protective earth) requirements shall be in accordance with the manufacturer's specifications.

5.4 Isolation of power sources

Each robot system shall have means to isolate each of its power sources. These means shall be located in such a way that no person will be exposed to hazards and they shall have a lockout/tagout capability. (For requirements of electrical supply disconnecting devices, see IEC 204-1.)

6 Design and construction of the robot

6.1 General

The robot manufacturer shall design and construct robots in accordance with the principles described in this clause and clause 5.

6.2 Ergonomic aspects

Application of ergonomic measures and data contributes to improvement of the safety level by making task completion easier and by decreasing the number of human errors during interventions (e.g. repairing, maintenance, checking, programming, operating). The following requirements apply.

- Design of robot elements, on which human intervention is intended, shall take into account human characteristics such as size, posture, strength, and movements (see ISO 6385).
- Human-machine interfaces (including operating and programming devices, signalling units such as portable control devices, control panels, computer terminals, and software-driven features from application programs) shall be designed and arranged to minimize difficulty for the individual user.
- Pertinent information shall be provided such as clearly indicating robot working modes and displaying the reason for unprogrammed robot stops.

6.3 Mechanical aspects

6.3.1 General

Whenever practicable, hazards arising from the moving parts of the robot shall be eliminated in the initial design. If they cannot be eliminated, then suitable safeguards shall be incorporated as part of the design, and if this is not practicable, provision shall be made for safeguards to be incorporated at a later stage.

6.3.2 Limitation of range of motion

The design of the robot shall not prevent the provisions of means for limiting the range of motion of the primary axes. When a method of limiting the range of motion is required by the designed use, it shall comply with one of the following.

- Mechanical stops may be provided. These should be adjustable and shall be capable of stopping the robot at any adjusted position when it is carrying its rated load at maximum velocity.
- Alternative methods of limiting the range of motion may be provided only if they are designed, constructed, and installed to achieve the same level of safety as the mechanical stops. This may include using the robot controller and limit switches according to IEC 204-1.

6.3.3 Covers and enclosures

Electrical, hydraulic, etc. equipment which constitute a hazard shall be provided with fixed covers or enclosures. Access shall not be required during operation of the robot. Removal of the fixed covers and enclosures shall require the use of a tool.

6.3.4 Transportation

For the purposes of transportation, hooks, eye-bolts, etc. shall be provided when required. They shall be located so that if they are used properly, unintended movement during transportation is prevented. The shipping weight should also be marked on the robot.

6.3.5 Mounting provisions

Means shall be provided for securely mounting the robot to provide stable operation during all designed operating conditions.

6.4 Control aspects

6.4.1 Panel arrangement

Actuating control devices shall be arranged, identified, and protected against unintended or accidental operation in accordance with IEC 204-1.

6.4.2 Emergency stop

Manually operated emergency stop devices shall be in accordance with IEC 204-1. Each robot shall have provisions to connect external emergency stop devices, safeguards, or interlocks to the emergency stop circuit.

It shall be necessary to reset manually the emergency stop circuit before any robot motion may be initiated. The resetting of the emergency stop circuit by itself shall not initiate any motion. Where an emergency stop or power fault causes the loss of critical logic or memory states, a reset sequence of the logic or memory shall be necessary before operation may be initiated.

6.4.3 Safety stop

When a safety stop circuit is provided, each robot shall have provisions to connect safeguards and interlocks to this circuit. It shall be necessary to reset the power to the machine actuators before any robot motion may be initiated. The resetting of the power to the machine actuators by itself shall not initiate any operation (see IEC 204-1: —, 9.2.2, category 1).

6.4.4 Electrical connectors

Electrical connectors used on robots which can cause hazardous motion when mismatched shall be keyed or labelled. Electrical connectors which could cause hazardous motion of the robot if they are separated or if they break away shall be designed and constructed so as to guard against unintended separation.

6.4.5 Pendant

When a pendant is provided, the following design requirements shall apply.

a) The pendant shall be designed in accordance with known ergonomic principles (see 6.2) so that it can be reliably used while it is being carried.
b) As long as the pendant is being used in the safeguarded space, it shall not be possible to switch the robot to automatic operation.

c) The pendant shall have an emergency stop device.
d) A pendant intended to initiate robot motion by personnel who are within the safeguarded space shall be provided with hold-to-run control device(s).
e) The robot control shall be designed so that when the robot is placed under pendant control, all robot motion shall only be initiated from the pendant.
f) All motion of the robot that is initiated from the pendant shall be at no greater than the reduced speed. What constitutes an acceptable reduced speed will depend on the forces exerted by the robot and the use of the robot (e.g. layout of installation). The reduced speed should not exceed 250 mm/s as measured at the mechanical interface.

Exceptions to f): When a speed greater than the reduced speed is required (e.g. for verification of a task program), it shall require a deliberate action by the operator (e.g. with a key switch) to select this method of operation. Robot motion shall only be initiated by the use of hold-to-run control device(s) and an enabling device while personnel is inside the safeguarded space (see 6.4.6).

6.4.6 Enabling device

When an enabling device is provided as part of the robot system, it shall be designed to allow robot motion or other functions in one position only. In any other position, hazardous motion or functions shall be stopped safely. Operation of the device by itself shall not initiate hazardous motion or functions.

When an enabling device is required (e.g. for robot motion at a speed greater than reduced speed), it shall be connected to the safety stop or another stop circuit with an equivalent level of safety.

The enabling device may be deactivated by design when either

- there are no persons within the safeguarded space, or
- the robot motion is not greater than the reduced speed.

The enabling device may be part of the pendant or may be a separate device.

6.5 Provisions for robots with arm-moving programming

For robots which are programmed by manually leading the arm, provisions shall be made to switch the power off safely during programming and counterbalancing where required.

6.6 Provisions for emergency movement

Means shall be provided for the movement of robot axes for emergency purposes. These means are for example:

a) with power off:
  - relief valves to depressurize systems under pressure;
  - manual release of power-actuated brakes provided that weight-balancing exists;
b) with power on:
  - manual control facilities of power-piloted valves/drives;
  - control facilities to start counter motions.

6.7 Power sources

Robots shall be designed and constructed so that any loss, restoration, or variation in the power sources will not result in hazardous motion of the robot.

6.8 Stored energy

Means shall be provided for the controlled release of stored energy. This energy source may be in the form of (but is not limited to) fluid pressure accumulators, capacitors, springs, counter balances, and flywheels. An appropriate label shall be affixed to each stored energy source.

6.9 Interference(s)

The design and construction of the robot shall incorporate good engineering practices to minimize the effects of interference(s) which can affect safety. These can include electromagnetic interference (EMI), electrostatic discharge (ESD), radio frequency interference (RFI), heat, light, vibration, etc.

NOTE: The provisions for interference requirements and testing are found in IEC 204-1.

6.10 Facilities for selection of operating conditions

Facilities shall be provided to ensure unambiguous selection of operating conditions. These facilities shall also indicate the selected operating condition. The selection of different operating conditions shall not in itself cause robot motion or start other functions.

When the protection of safeguards is suspended by the selection of the operating condition (e.g. for set-up, teaching, program verification), this should only be possible when the facilities for selecting the operating conditions are secured (e.g. key selection). Automatic (normal) operation shall be prevented during suspension of the safeguards and robot motion shall be at reduced speed [see 6.4.5 f) for exception].

6.11 Requirements for documentation

For requirements for documentation supplied by the robot manufacturer, see 10.1.

7 Design and safeguarding of the robot system

7.1 General

The robot system manufacturer/supplier shall design and construct robot systems in accordance with the principles described in this clause and clause 5.

7.2 Design

7.2.1 General

The robot system shall be designed in accordance with the manufacturer's specifications so that personnel who operate, program, and maintain the system can be appropriately safeguarded. All environmental conditions shall be evaluated to ensure compatibility of the robot and the robot system with the anticipated operational conditions. These conditions include, but are not limited to, explosive mixtures, corrosive conditions, humidity, dust, temperature, electromagnetic interference (EMI), radio frequency interference (RFI), and vibration.

7.2.2 Safeguarded space

The risk assessment shall determine the additional space required beyond the restricted space to define the safeguarded space (see figure 1).

7.2.3 Physical arrangement of the robot system

7.2.3.1 Control enclosures should be installed outside the safeguarded space. When they are installed inside the safeguarded space, they shall be located and fixed in such a way that the requirements of this International Standard regarding safety of persons within the safeguarded space can be met (see also 7.6 and clause 8).

7.2.3.2 Robot systems shall be designed to avoid trapping and collision between the moving parts of the robot and other fixed or moving objects.

The layouts shall be designed in such a way that between moving parts of the robot and objects in the environment (e.g. pillars of the structure, ceiling joists, fences, supply leads) sufficient clearance is available. This rule does not apply to associated equipment in order to allow it to perform its task (e.g. tool flanges, indexing tables, transport equipment, automatic lathes, processing centres, presses, injection moulding machines).

7.2.3.3 When a limitation of the restricted space, by limiting the range of motion of the primary axes, is required by the plan, limiting devices shall be provided in accordance with 6.3.2. The limiting devices shall be correctly adjusted and secured.

7.2.3.4 End effectors shall be designed and constructed, or safeguarded, so that
- power failure does not cause release of the load or result in a hazardous condition, and
- the static and dynamic forces created by the load and the end effector together are within the load capacity and dynamic response of the robot.

7.2.3.5 When it is intended that operators will perform manual operations associated with the robot, such as loading and unloading of parts, this shall be taken into account in the arrangement of the robot system, either by providing loading devices so that the operator cannot access the hazardous area, or by providing appropriate safeguards for the manual activity.

7.2.4 Shut down

Shut down (removal of power) to the robot system or any associated equipment shall not result in a hazardous condition.

7.2.5 Emergency stop

Each robot system operator station shall have a readily accessible emergency stop device. The manual intervention and reset procedure to restart the robot system after an emergency stop shall take place outside the restricted space.

7.2.6 Control from remote locations

Any robot that can be controlled from a remote location shall be provided with an effective means that shall prevent hazardous conditions of the robot being initiated from any other location.

For robot systems that can be operated from a remote location (e.g. over a communications network), a means shall be provided (e.g. a key operated switch) to ensure that no commands can initiate hazardous conditions from the remote location when in local control.

7.3 Safeguards

7.3.1 Guards

7.3.1.1 Fixed guards

Fixed guards shall
a) be constructed to withstand foreseeable operational and environmental forces,
b) prevent access to the safeguarded space except through openings associated with interlocking or presence sensing devices,
c) be permanently fixed in position and only be removable with the aid of a tool, and
d) be free of sharp edges and projections and shall not themselves be a hazard.

7.3.1.2 Interlocking guards

a) The interlock and the guard with which it operates should be designed, installed, and adjusted so that when in use
   1) the interlock prevents the robot system from automatic operation until the guard is closed. The closure of the guard shall not be the control to restart automatic operation. This shall be a deliberate action at the control station (see 7.6), and
   2) either the guard remains locked closed until the risk of injury from the hazard has passed (interlocking guard with guard locking) or opening the guard while the robot system is working gives a stop or emergency stop instruction (interlocking guard).

   When an interlock has been activated, it shall be possible to restart the machine from the stopped position provided that this does not create other hazards.

   Interruption of the power sources may be sufficient to eliminate the hazard before access is possible. Where the hazard cannot be eliminated immediately by power interruption, the interlocking system shall need to include a guard locking and/or a braking system.

   Where whole-body access to the safeguarded space can be gained through an interlocking door, a device which prevents inadvertent closing of the door should be provided.

   Care should be taken to ensure that actuation of an interlock installed to protect against one hazard (e.g. stopping hazardous motion of the robot system) does not create a different hazard (e.g. the release of hazardous substances into the work zone).

b) Selection of the preferred system of interlocking for a particular application shall take account of the risk assessment (see 4.2.2).

c) The design and construction of the interlocking systems shall comply with 5.1 of this International Standard.

7.3.2 Presence sensing devices

Whenever presence sensing devices are used for safety purposes, they shall comply with the following.

a) A presence sensing device shall be installed and arranged so that persons cannot enter and reach into a hazardous area without activating the device or cannot reach the restricted space before the hazardous conditions have ceased. Barriers used in conjunction with the presence sensing device may be required to prevent persons from bypassing the device.
b) Their operation shall not be adversely affected by any of the environmental conditions for which the system was intended.
c) When a presence sensing device has been activated, it may be possible to restart the robot system from the stopped position provided that this does not create other hazards.
d) Resumption of robot motion shall require the removal of the sensing field interruption. This shall not be the control to restart automatic operation (see 7.6).

7.4 Awareness means

The following awareness means may be used in addition to but not as a substitute for the safeguards previously described elsewhere in this International Standard.

7.4.1 Awareness barrier

An awareness barrier shall be constructed and installed so as to prevent inadvertent entry into the restricted space.

7.4.2 Awareness signal

An awareness signal device shall be constructed and located such that it shall provide a recognizable audible or visual signal to persons of an approaching or present hazard. When awareness signals in the form of light are used to warn of hazards in the restricted space, sufficient devices shall be used and located so that the lights can be seen by all persons in the proximity of the space.

Audible awareness devices shall have a distinctive sound of greater intensity than the ambient noise level.

7.5 Safe working procedures

It is recognized that for certain phases of the robot system life (e.g. commissioning, process changeover, cleaning, and maintenance) it may not be possible to design completely adequate safeguards to protect against every hazard or that certain safeguards may be suspended. Under these conditions, appropriate safe working procedures shall be used.

7.6 Reset of safeguards

Reestablishing the interlocked gate or presence sensing device field shall not in itself restart automatic operation. Restarting the system shall require a deliberate action from outside the safeguarded space. The restarting device shall be located so that it cannot be reached from inside the safeguarded space and should be located in a manner to afford a view of the safeguarded space.

7.7 Requirements for documentation

For requirements for documentation supplied by the robot system manufacturer, see 10.2.

8 Use and care

8.1 General

This clause specifies the requirements for safety during teach programming, program verification, automatic operation, trouble shooting, and maintenance. The user shall ensure that the safeguarding methods are provided, utilized, and maintained for each operation associated with the robot system and in particular for personnel other than those utilizing the teach pendant or enabling device.

The user shall ensure that a pendant not connected to the robot control shall be inaccessible.

8.2 Automatic (normal) operation

Automatic operation shall only be permissible when

a) the intended safeguards are in place and functioning,
b) no personnel are present within the safeguarded space, and
c) proper safe working procedures are followed.

8.3 Programming

Wherever possible, programming shall be performed with all persons outside the safeguarded space. When it is necessary to perform programming with personnel inside the safeguarded space, the protective effectiveness of the safeguards (e.g. door interlocking, presence sensing devices) may be suspended by means of selection of operating conditions according to 6.10 provided that additional means of safeguarding as described below are provided. (The following applies to teach programming.)

8.3.1 Prior to programming

The programmer shall be trained on the type of robot used in the actual robot system and shall be familiar with the recommended programming procedures including all of the safeguarding methods.

The programmer shall visually check the robot system and the safeguarded space to ensure that extraneous conditions which can cause hazards do not exist. Where required for programming, the pendant shall be tested to ensure proper operation. Any faults or failures shall be corrected prior to programming. Where power to the robot actuators is not required for programming, it shall be shut off (counter balances where necessary shall remain effective).

Before entering the safeguarded space, the programmer shall ensure that all necessary safeguards are in place and functioning. The programmer shall be required to initiate programming operation prior to entering the safeguarded space. Automatic operation shall not be possible.

8.3.2 During programming

During programming, only the programmer shall be allowed in the safeguarded space and the following conditions shall be met.

- The robot system shall be under the solo control of the programmer within the safeguarded space.
- The controls of the pendant shall be used as intended (see 6.4.5).
- The robot system shall not respond to any remote commands or conditions that would cause hazardous conditions.

- Movement of other equipment in the safeguarded space which can present a hazard shall either be prevented or under the sole control of the programmer. When under control of the programmer, it shall require deliberate action on the part of the programmer separate from the action to initiate robot motion.
- All robot system emergency stop devices shall remain functional.

8.3.3 Returning to automatic operation

The programmer shall return the suspended safeguards to their original effectiveness prior to initiating automatic operation of the robot system.

8.4 Programming data

Wherever possible, a record of the task programs together with any modifications should be maintained.

Programmed data that are stored on a transportable medium (e.g. paper, magnetic) shall be stored in a suitably protected environment when not in use.

8.5 Program verification

When visual examination of the robot system response to the task program is necessary as part of the verification procedure, it should be made with all persons outside the safeguarded space. When it is necessary to perform program verification with personnel inside the safeguarded space, the following shall apply.

a) Program verification shall initially be performed at reduced speed. The requirements of 8.3 shall apply, except that motion control only requires a hold-to-run control or an enabling device.
b) When it is necessary to examine the movement of the robot at full (operational) speed, the following requirements shall apply:
    1) suspension of the reduced speed by means that require deliberate action by the programmer only (e.g. the use of a key switch);
    2) an enabling device or a device with an equivalent safety level shall be used by personnel within the safeguarded space;
    3) safe working procedures are established to minimize the exposure of personnel to hazards within the safeguarded space.

8.6 Trouble shooting

Trouble shooting shall be performed from outside the safeguarded space. When this is not practicable, and the design of the robot system has taken into account the necessity of performing trouble shooting from within the safeguarded space, the following requirements shall apply:

- personnel responsible for trouble shooting are specifically authorized and trained for these activities;
- personnel entering the safeguarded space shall use an enabling device to allow motion of the robot;
- safe working procedures are established to minimize the exposure of personnel to hazards within the safeguarded space.

8.7 Maintenance

The robot or robot system shall have an inspection and maintenance programme to ensure continued safe operation of the robot or robot system. The inspection and maintenance programme shall take into account the robot and robot system manufacturer's recommendations.

8.7.1 Personnel who perform maintenance or repairs on robots or robot systems shall be trained in the procedures necessary to perform safely the required tasks.

8.7.2 Personnel who maintain and repair robot systems shall be safeguarded from hazards.

8.7.3 Where possible, maintenance shall be performed from outside the safeguarded space by placing the robot arm in a predetermined position.

When it is necessary to perform maintenance within the safeguarded space, selection of the preferred means of safeguarding described under 8.7.3.1 and 8.7.3.2 shall take account of risk assessment.

8.7.3.1 The robot system shall be shut off using a lockout/tagout procedure.

8.7.3.2 Alternatively, intervention within the safeguarded space while power is available to the robot shall require the following.

a) Prior to entering the safeguarded space, the following procedure shall be performed:
    1) a visual inspection of the robot system shall be made to determine if any conditions exist that are likely to cause malfunctions;
    2) if pendant controls are to be used, they shall be functionally tested prior to such use to ensure their proper operation;
    3) if any damage or malfunction is found, required corrections shall be completed and retesting shall be performed before personnel enter the safeguarded space.
b) Personnel performing maintenance or repair tasks within the safeguarded space shall have total control of the robot or robot system:
    1) the control of the robot shall be removed from automatic;
    2) the robot shall not respond to any remote signals;
    3) all robot system emergency stop devices shall remain functional.
c) The suspended safeguards shall be returned to their original effectiveness prior to initiating automatic operation of the robot system.

9 Installation, commissioning and functional testing

9.1 General

This clause contains provisions and requirements for installing and functional testing of the robot system prior to its use in normal operation.

9.2 Installation

The robot system shall be installed in accordance with the manufacturer's requirements. The safeguarding methods shall be identified by the hazard analysis and the risk assessment. ISO 9946 shall be consulted for additional guidance during installation. The user shall review the safety requirements to ensure that the appropriate safeguards are applied and operational prior to use in production.

9.3 Commissioning and functional testing

This subclause defines the procedures that shall be followed during the testing of robots or robot systems after installation or relocation. It also applies to robots or robot systems after modifications (e.g. changes in hardware or software, replacement of parts, adjustments) and after maintenance or repairs that can adversely affect their operation.

9.3.1 Designation of the restricted space

When the safeguarding methods are not in place prior to commissioning and functional testing, interim means of designating the restricted space shall be in place before proceeding.

9.3.2 Restriction of personnel

During the commissioning and functional testing, personnel shall not be allowed in the safeguarded space until the safeguards are functional.

9.3.3 Safety and operational verification

The manufacturer's instructions for commissioning and testing of the robot and/or the robot system shall be followed. An initial start-up procedure shall include, but is not necessarily limited to, the following.

a) Before applying power, verify that
    1) the robot has been properly mechanically mounted and is stable,
    2) the electrical connections are correct and that the power (i.e. voltage, frequency, interference levels) is within specified limits,
    3) the other utilities (e.g. water, air, gas) are properly connected and within specified limits,
    4) the peripheral equipment is properly connected,
    5) the limiting devices that establish the restricted space (when utilized) are installed,
    6) the safeguarding means are applied, and
    7) the physical environment is as specified (e.g. lighting and noise levels, temperature, humidity, atmospheric contaminants).

b) After applying power, verify that
    1) the start, stop, and mode selection (including the key lock switches) control devices function as intended,
    2) each axis moves and is restricted as intended,
    3) emergency stop and safety stop (where included) circuits and devices are functional,
    4) it is possible to disconnect and isolate the external power sources,
    5) the teach and playback facilities function correctly,
    6) the safeguards and interlocks function as intended,
    7) other safeguarding is in place (e.g. barriers, warning devices),
    8) in reduced speed, the robot operates properly and has the capability to handle the product or workpiece, and
    9) in automatic (normal) operation, the robot operates properly and has the capability to perform the intended task at the rated speed and load.

9.3.4 Robot system restart procedures

A procedure for the restart of the robot system after hardware, software or task program modification, repair, or maintenance shall include but not necessarily be limited to the following:

a) check any changes or additions to the hardware prior to applying power;
b) functionally test the robot system for proper operation.

10 Documentation

10.1 Robot documentation to be supplied by the robot manufacturer

The robot documentation as a minimum shall contain:

a) identification of the robot;
b) robot characteristics according to ISO 9946;
c) physical environment specifications according to ISO 9946;
d) installation instructions according to ISO 9946;
e) instructions for use including:
    1) commissioning,
    2) programming,
    3) operation,
    4) restarting procedure, and
    5) maintenance.

These instructions shall include the response of the robot to the various controls and different operating conditions, and safety measures to be taken to avoid hazardous conditions.

The documentation shall inform about the training of personnel who will use the robot .

10.2 Robot system documentation to be supplied by the robot system manufacturer

The robot system documentation shall contain the documents of all the components included in the system with their identification (e.g. robot, associated equipment, safeguards).

It shall also as a minimum include the following:

a) a clear, comprehensive description of the robot system and its installation including mounting and connection to external power sources;
b) a description of foreseeable hazardous conditions and how to avoid them;
c) a description (including interconnecting diagrams) of the safeguards, interacting functions, and interlocking of guards with hazardous conditions particularly with interacting installations;
d) any further instructions for use specific to the system.

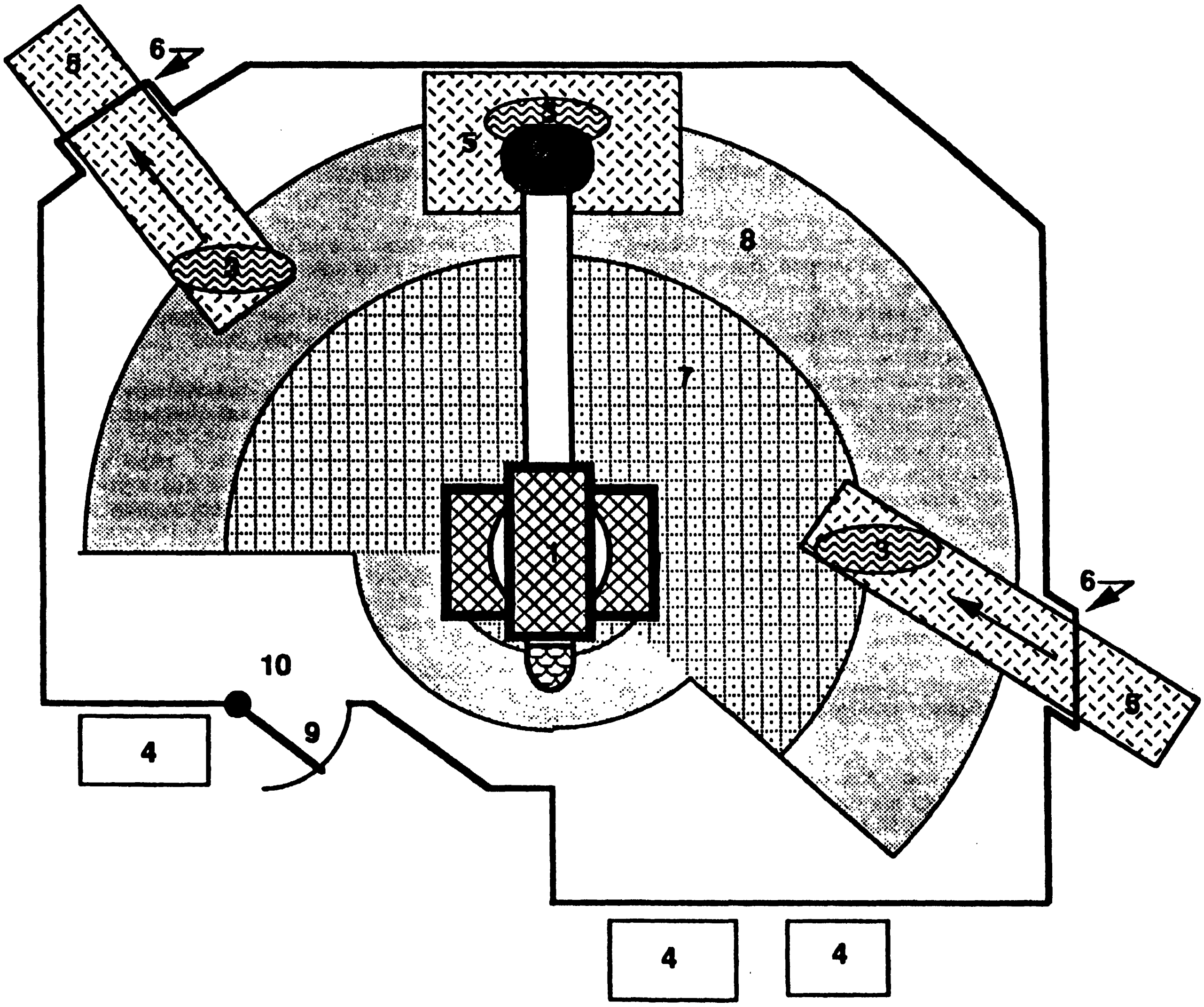
11 Training

The user shall ensure that personnel who program, operate, maintain, or repair robots or robot systems are adequately trained and demonstrate competence to perform their jobs safely. Training shall include, but is not limited to, the following:

a) a review of applicable standard safety procedures and the safety recommendations of the robot manufacturer(s) and the robot system designers;
b) a clear definition of assigned tasks;
c) identification and explanation of all control devices and their functions used in performing the assigned task;
d) identification of the hazards associated with the assigned task;
e) the designated method(s) of safeguarding including the safe working procedures from the identified hazards;
f) the method for testing or otherwise ensuring the proper functioning of the safeguards and interlocks.

Annex A
(informative)

Schematic diagram showing major elements of a robot system



1 –	Robot
2 –	End effector
3 –	Workpiece
4 –	Control or power equipment (control panel, hydraulic group)
5–	Associated equipment (e.g. conveyor, rotary table)
6 –	Safeguard (guard or presence sensing device)
7 –	Restricted space
8 (+7) –	Maximum space
9 –	Interlocked gate'
10–	Interlocking device

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